

# **ESTIMATION OF TIME OF CONCENTRATION USING TRIANGULATED IRREGULAR NETWORK METHOD**

by

EWE TEIK TSIA

Thesis submitted in fulfilment of the requirements  
for the Degree of  
Master of Science

OCTORBER 2015

## **ACKNOWLEDGEMENTS**

First of all, I wish to express my gratitude to my supervisor, Dr. Lau Tze Liang and co-supervisor, Professor Dr. Nor Azazi Bin Zakaria for their guidance and advice throughout my thesis study.

Secondly, I would like to extend my appreciation to MES Innovation Sdn. Bhd. and its management in their financial support and help in the software development. I might not go this far without them.

I would like to thank the officers and technical staffs in River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia; and Civil Engineering School (PPKA), Universiti Sains Malaysia for their helps, especially Mr. Mohamad Firdaus Talib and Mr. Mohd Sufian Osman. Their helps are deeply appreciated.

Besides, I would like dedicate my regards to my friends for giving me their generous helps and supports especially my senior, Engr. Leow Cheng Siang and my friend Ar. Yeoh Chen Lim.

Lastly and most importantly, I would like to give my deepest thanks to my late mother for her undaunted patience and endless support to me. Her love will always be with me forevermore. Also to my family for their encouragement in my pursue of this Master degree. Without their great support, this thesis would be impossible.

## TABLE OF CONTENTS

	Page
Acknowledgements	ii
Table of Contents	iii
List of Tables	vii
List of Figures	ix
List of Symbols	xiv
Abstrak	xv
Abstract	xvii
<b>CHAPTER 1: INTRODUCTION</b>	
1.1 Research Background	1
1.2 Time of Concentration	1
1.3 Problem Statements	4
1.4 Research Objectives	11
1.5 Research Scopes	11
1.6 Thesis Outline	11
<b>CHAPTER 2: LITERATURE REVIEW</b>	
2.1 Urban Hydrology	13
2.2 Flow Time and Runoff Estimation Methods	23
2.2.1 Overland Flow Time	23
2.2.2 Kerbed Gutter Flow Time	25
2.2.3 Open Channel Flow Time	27

2.2.4	Pipe Flow Time	28
2.2.5	Rational Method	28
2.2.6	Hydrograph Method	29
2.3	Time-area Method	31
2.3.1	Catchment Characteristics	31
2.3.2	Catchment and Stream Line Delineation	32
2.3.3	Depression and Flat Area Handling	34
2.3.4	Area of Isochrones	37
2.4	Triangulated Irregular Networks (TIN) Method	38
2.5	Grid Method	41
2.6	Conventional Method	43
2.7	Comparison between TIN Method and Grid Method	44
2.8	Other Methods	45
2.9	Summary	47
 <b>CHAPTER 3: METHODOLOGY</b>		
3.1	Introduction	50
3.2	Study Site Construction	53
3.2.1	Setting Up and Construction	53
3.2.2	Profiling	57
3.2.3	Instrumentation	58
3.2.4	Data Collection	60
3.3	TIN Algorithm	61

3.3.1	Development of TIN Algorithm	61
3.3.2	TIN Algorithm Input	62
3.3.3	TIN Algorithm Output	62
3.4	Calculation Method	63
3.4.1	Flow Discharge Data and Rainfall Data	63
3.4.2	TIN Method Calculation	64
3.4.3	Grid Method Calculation	67
3.4.4	Conventional Method Calculation	73
3.5	Research Tools	76
3.6	Accuracy of Measurement Methods	77
3.6.1	Flow Discrepancy Comparison and Correlation Coefficient	77
3.6.2	Peak Flow Comparison	79
3.6.3	Total Runoff Volume	81
3.7	Summary	83
 <b>CHAPTER 4: RESULTS AND DISCUSSION</b>		
4.1	Introduction	84
4.2	Rainfall Data Analysis	84
4.3	Time-Area Method Calculation	85
4.4	Comparison among Hydrograph Results	85
4.5	Comparison among Three Methods	90
4.5.1	TIN Method	90
4.5.2	Grid Method	91

4.5.3	Conventional Method	92
4.6	Accuracy Comparison among Three Methods	93
4.6.1	Flow Discrepancy Comparison	93
4.6.2	Total Runoff Volume Comparison	102
<b>CHAPTER 5: CONCLUSION AND RECOMMENDATIONS</b>		
5.1	Conclusion	104
5.2	Recommendations	105
<b>REFERENCES</b>		107
<b>APPENDIXES</b>		
Appendix A	TIN Algorithm Source Code	
Appendix B	Rainfall Data	
Appendix C	Flow Meter Data	
Appendix D	Time-area Method Calculation Spreadsheet	
Appendix E	Time of Concentration Calculation Spreadsheet for TIN Method and Grid Method	

## LIST OF TABLES

		<b>Page</b>
Table 1.1	Tabulation of the area between the isochrones	8
Table 2.1	Probability of rainfall occurrence and percentage of chances occur in a given year (Parzybok, 2011)	18
Table 3.1	Value of Manning's Roughness coefficient, $n$ (JPS, 2011)	52
Table 3.2	TIN method calculation table	65
Table 3.3	Recommended intervals for design rainfall excess (JPS, 2011)	66
Table 3.4	Grid method calculation table	71
Table 3.5	Comparison among the peak flow results	80
Table 3.6	Percentage of discrepancy in different methods compared with observed data	81
Table 3.7	The comparison among observed and calculated results	83
Table 4.1	Peak flow for observed data and calculated values	90
Table 4.2	Percentage of difference for peak flow	91
Table 4.3	Flow comparison for Set 1 data	93
Table 4.4	Correlation coefficient for Set 1 data	93
Table 4.5	Flow comparison for Set 2 data	94
Table 4.6	Correlation coefficient for Set 2 data	94
Table 4.7	Flow comparison for Set 3 data	95
Table 4.8	Correlation coefficient for Set 3 data	95
Table 4.9	Flow comparison for Set 4 data	96
Table 4.10	Correlation coefficient for Set 4 data	96

Table 4.11	Flow comparison for Set 5 data	97
Table 4.12	Correlation coefficient for Set 5 data	97
Table 4.13	Flow comparison for Set 6 data	98
Table 4.14	Correlation coefficient for Set 6 data	98
Table 4.15	Flow comparison for Set 7 data	99
Table 4.16	Correlation coefficient for Set 7 data	99
Table 4.17	Flow comparison for Set 8 data	100
Table 4.18	Correlation coefficient for Set 8 data	100
Table 4.19	Average correlation coefficient between Observed data against TIN, Grid and Conventional methods	102
Table 4.20	Average accuracy for TIN, Grid and Conventional methods	102
Table 4.21	Total Runoff Volume and the average different among TIN, Grid and Conventional compare with Observed data	103



## LIST OF FIGURES

		<b>Page</b>
Figure 1.1	Rainfall phenomena	2
Figure 1.2	Topography with 1m contour line	6
Figure 1.3	Superimpose of grid and contour line	6
Figure 1.4	Re-sampling grid with z-coordinates in every intersection	7
Figure 1.5	Travel time area calculated from z-coordinates and the isochrones lines are plotted in 5 minutes time interval	7
Figure 1.6	Area of isochrones is obtained from isochrones lines contours	8
Figure 1.7	Grid points are obtained on contour lines	9
Figure 1.8	Grid meshing	9
Figure 1.9	Blind zone in Grid method	10
Figure 2.1	Flood prone area in Malaysia (Abdullah 2004)	14
Figure 2.2	Flooding in Kota Tinggi in December 2006 although the catchment elevation is relatively high (New Straits Times, 2006)	15
Figure 2.3	Flooding in Kuantan town on 3 December 2013 (Sinar Harian, 2013)	15
Figure 2.4	(a) The residents of Kuantan using a boat to survey the condition of their homes; (b) A family waiting out the floods in their house (The Star Online, 2013)	15
Figure 2.5	Flooding in Kelantan on 24 December 2014 (Agence France-Presse, 2014)	16
Figure 2.6	A flooded village in Tumpat, Kelantan (Agence France-Presse, 2014)	16
Figure 2.7	IDF curve (MES - PondCAD, 2013)	19

Figure 2.8	Pre-development (left) and post-development (right)	19
Figure 2.9	Post-development with stormwater retention management	20
Figure 2.10	Runoff hydrograph	20
Figure 2.11	Hypothetical catchment and Time-area curve (NWS & NOHRSC, 1998)	22
Figure 2.12	Kerbed Gutter Flow Time at different flow length and surface slope	26
Figure 2.13	Path flow in a hydrologic model	34
Figure 2.14	Depression area (MES-EW3D, 2013)	35
Figure 2.15	Direction of flow over one flat area (Zhu et al., 2006)	36
Figure 2.16	Result of the combined gradient algorithm (Bartak, 2009)	37
Figure 2.17	Delaunay triangulation method (Ianko, 2003)	40
Figure 2.18	The Eight-Direction (D8) Pour Point Model (Kull et al., 1998)	42
Figure 2.19	Catchment isochrones (JPS, 2000)	44
Figure 2.20	Time-area curve (JPS, 2000)	44
Figure 3.1	Research methodology flow chart	50
Figure 3.2	Site location (Google Map, 2013)	53
Figure 3.3	Site setting-up	54
Figure 3.4	Backfilling	55
Figure 3.5	Backfilling after soil settlement	55
Figure 3.6	<i>Axonopus Compressus</i> (cow grass)	56
Figure 3.7	Cross-section of the man-made mountain	56

Figure 3.8	Site formed and stabilised	57
Figure 3.9	Electronic Distance Measurement (EDM)	57
Figure 3.10	Site topography	58
Figure 3.11	Schematic diagram of flow measuring instrument	59
Figure 3.12	Flow measuring instrument at site	59
Figure 3.13	Rain gauge station	60
Figure 3.14	TIN Algorithm flow chart	61
Figure 3.15	Observed rainfall excess and runoff hydrograph	63
Figure 3.16	Computer-based TIN model	64
Figure 3.17	TIN model with the area between isochrones contours	66
Figure 3.18	Rainfall excess and simulated runoff hydrograph (TIN method)	67
Figure 3.19	Topography survey plan overlaid with a square grid	68
Figure 3.20	Computed elevation values for all intersection points	69
Figure 3.21	Length measurement from grid intersection point to the outlet point	70
Figure 3.22	Travel time contour plan	72
Figure 3.23	Rainfall excess and simulated runoff hydrograph (Grid method)	73
Figure 3.24	Hydrologically most remote point and most downstream point	74
Figure 3.25	A contour of 5 minutes time interval	75
Figure 3.26	Rainfall excess and simulated runoff hydrograph (Conventional method)	76
Figure 3.27	The comparison table (Set 3) among the observed and computed flow using TIN, Grid and Conventional methods	78

Figure 3.28	Comparison among the observed and computed flow using TIN, Grid and Conventional methods	79
Figure 3.29	A selected example of compiled runoff hydrograph for the observed and calculated data using TIN, Grid and Conventional methods	80
Figure 3.30	Flow volume of the calculated data using Conventional method	81
Figure 3.31	Flow volume of the calculated data using Grid method	82
Figure 3.32	Flow volume of the calculated data using TIN method	82
Figure 3.33	Flow volume of the observed data	82
Figure 4.1	Hydrograph for rainfall event on 3 Jan 2014 (Set 1)	86
Figure 4.2	Hydrograph for rainfall event on 6 Jan 2014 (Set 2)	86
Figure 4.3	Hydrograph for rainfall event on 5 April 2014 (Set 3)	87
Figure 4.4	Hydrograph for rainfall event on 6 April 2014 (Set 4)	87
Figure 4.5	Hydrograph for rainfall event on 10 May 2014 (Set 5)	88
Figure 4.6	Hydrograph for rainfall event on 12 May 2014 (Set 6)	88
Figure 4.7	Hydrograph for rainfall event on 13 May 2014 (Set 7)	89
Figure 4.8	Hydrograph for rainfall event on 8 Dec 2014 (Set 8)	89
Figure 4.9	Area of isochrones could be equally divided	92
Figure 4.10	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 1 data (3 January 2014)	94
Figure 4.11	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 2 data (6 January 2014)	95
Figure 4.12	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 3 data (5 April 2014)	96
Figure 4.13	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 4	97

	data (6 April 2014)	
Figure 4.14	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 5 data (10 May 2014)	98
Figure 4.15	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 6 data (12 May 2014)	99
Figure 4.16	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 7 data (13 May 2014)	100
Figure 4.17	Comparison among the observed and computed flow using TIN, Grid and Conventional methods for Set 8 data (8 Dec 2014)	101

## LIST OF SYMBOLS

Symbol	Definition
$T_r$	Average Recurrence Interval (year)
$P$	Annual Exceedance Probability (%)
$t_c$	Time of concentration (minute)
$t_o$	Overland sheet flow path time (minute)
$t_d$	Drainage flow time (minute)
$t_g$	Flow time for kerbed gutter (minute)
$t_p$	Travel time in the pipe (minute)
$n$	Manning's roughness
$L_o$	Overland sheet flow path (m)
$L_d$	The length from the $L_o$ to streamline matching point to the catchment outlet (m)
$S$	Slope of overland surface (%)
$V$	The flow velocity (m/s)
$t_{ci}$	The travel time from Grid / TIN intersection to the outlet (minute)
$t_{oi}$	The travel time from Grid / TIN intersection to the streamline (minute)
$t_{di}$	The travel time from streamline matching point to the outlet (minute)

## **ANGGARAN MASA PENUMPUAN DENGAN MENGGUNAKAN KAEDAH RANGKAIAN PENYEGITIGA TIDAK TERATUR**

### **ABSTRAK**

Di Malaysia, Manual Saliran Mesra Alam (MSMA) telah mencadangkan dua kaedah pengiraan untuk mendapatkan luas antara isokron yang telah diamalkan secara meluas pada masa ini. Mereka adalah kaedah Grid dan kaedah Konvensional. Tetapi, kaedah-kaedah ini menimbulkan masalah yang tersendiri. Walaupun kaedah Grid adalah lebih terperinci dan tepat apabila dibandingkan dengan kaedah Konvensional, ia adalah amat membosankan dan memakan masa. Kaedah Konvensional sebaliknya adalah lebih mudah untuk digunakan. Tetapi, keputusannya tidak konsisten. Keputusannya adalah sangat subjektif kerana ia bergantung kepada pengalaman dan penilaian setiap pengguna. Justeru, kaedah pengiraan baru yang dikenali kaedah Rangkaian Penyegitiga Tidak Teratur (TIN) telah direka dan dibangunkan dalam kajian ini untuk meningkatkan pengiraan kaedah Masa-Luas. Kaedah ini adalah berasaskan komputer dan dengan itu algoritma kaedah TIN dibangunkan. Algoritma kaedah TIN telah dijelaskan dalam kajian ini. Satu tapak kajian telah dibina dan lapan set data hujan dikumpul. Semua hasil pengiraan daripada setiap kaedah disahkan dengan data tapak yang dikumpul untuk membandingkan ketepatannya. Siasatan ke atas kecekapan dan kebolehpercayaan kaedah-kaedah ini juga dijalankan dalam kajian ini. Perbandingan ini menunjukkan bahawa kaedah TIN mempunyai ketepatan yang lebih tinggi. Dalam perbandingan pekali korelasi antara kaedah yang ada, kaedah TIN mempunyai ketepatan purata 0.988, kaedah Grid mempunyai ketepatan purata 0.936 dan kaedah Konvensional mempunyai ketepatan purata 0.948. Apabila mengira peratus perbezaan mereka terhadap data yang dicerap, kaedah TIN mempunyai perbezaan purata 14.29%, kaedah Grid mempunyai perbezaan purata

25.67% dan kaedah konvensional mempunyai perbezaan purata 24.52%. Apabila menggunakan aliran puncak bagi perbezaan terhadap data yang diperhatikan, keputusan menunjukkan bahawa kaedah TIN mempunyai perbezaan purata 3.48%, kaedah Grid adalah 5.88% dan kaedah konvensional ialah 7.72%. Akhir sekali, dengan menggunakan jumlah isipadu aliran, kaedah TIN hanya mempunyai 0.19% perbezaan dengan data yang diperhati, kaedah Grid mempunyai 0.43% dan kaedah Konvensional mempunyai perbezaan sebanyak 4.80%. Kaedah TIN menunjukkan ketepatan dan kebolehpercayaan yang lebih tinggi berbanding dengan dua kaedah yang lain. Selain itu, kajian ini juga menunjukkan bahawa algoritma kaedah TIN yang baru dibangunkan adalah lebih mudah untuk digunakan, memakan masa yang kurang dan lebih dipercayai.



# **ESTIMATION OF TIME OF CONCENTRATION USING TRIANGULATED IRREGULAR NETWORK METHOD**

## **ABSTRACT**

In Malaysia, Manual Saliran Mesra Alam (MSMA) has proposed two calculation methods to obtain areas between the isochrones that have been widely practiced at the moment. They are Grid method and Conventional method. However, these methods pose certain problems of their own. Although the Grid method is more detail and accurate when compared to the Conventional method, but that is extremely tedious and time consuming. Conventional method on the other hand is simpler to use. But, the results are not consistent. The results are very subjective because it depends on each user's experience and judgement. Therefore, a new calculation method named Triangulated Irregular Network (TIN) method has been designed and developed in this research to improve the Time-Area method calculation. This method is computer based and thus the algorithm of TIN method was developed. The algorithm of the TIN method is explained in this research. A study site was constructed and eight sets of rainfall data were collected. All the results from each calculation method were verified with the collected site data to compare their accuracy. Investigation upon their efficiency and reliability were also presented in this research. The comparison showed that TIN method has higher accuracy. In the correlation coefficient comparison among the methods, TIN method has average accuracy of 0.988, Grid method has average accuracy of 0.936 and Conventional method has average accuracy of 0.948. When calculating their difference against the observed data in percentage, TIN method has average difference of 14.29%, Grid method has average difference of 25.67% and Conventional method has average difference of 24.52%. When using the peak flow

comparison for the difference against the observed data, the results shows that TIN method has average difference of 3.48%, Grid method has average difference of 5.88% and Conventional method has average difference of 7.72%. Lastly, the methods were compared using the total flow volume. It was demonstrated that the TIN method has different of 0.19%, Grid method has different of 0.43% and Conventional method has different of 4.80% when compared to the observed data. The TIN method has the highest accuracy and reliability among the three methods. Besides, this research also showed that the newly developed TIN method algorithm is easier to use, less time consuming and more reliable.

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Research Background**

Human beings have strived to survive on the surface of the Earth while learning to cope with its terrain. With their specialists, civil engineers are able to analysis, design and construct buildings and infrastructures on the Earth terrain. Throughout the years, civil engineers have tried every mean to represent phenomena and the characteristic of a terrain through mapping. To date, modern map generators employ a well-designed symbol system and well-established basis to represent three major characteristics of a terrain (Li et al., 2005). They are:

- a. measurability warranted by mathematical rules;
- b. overview provided by generalization; and
- c. intuition by symbolization.

In modern mapping, Triangulated Irregular Network (TIN) meshing is a map generators that include all the above-mentioned characteristics and most importantly, it offers a high accuracy in the terrain re-sampling (terrain modelling) process. After the new terrain has been generated, the travel time for each TIN intersection can be obtained by linear interpolation. With this set of travel time data, the area of isochrones can be generated for Time-area method calculation.

### **1.2 Time of Concentration**

When precipitation reaches the Earth, some will be evaporated, some will be retained by vegetation, some will infiltrated into the ground and some will

become the surface runoff (Figure 1.1). The surface runoff is an important component of the hydrologic response of a catchment because the period of time where the runoff travels to the downstream outlet formulates the time of concentration.

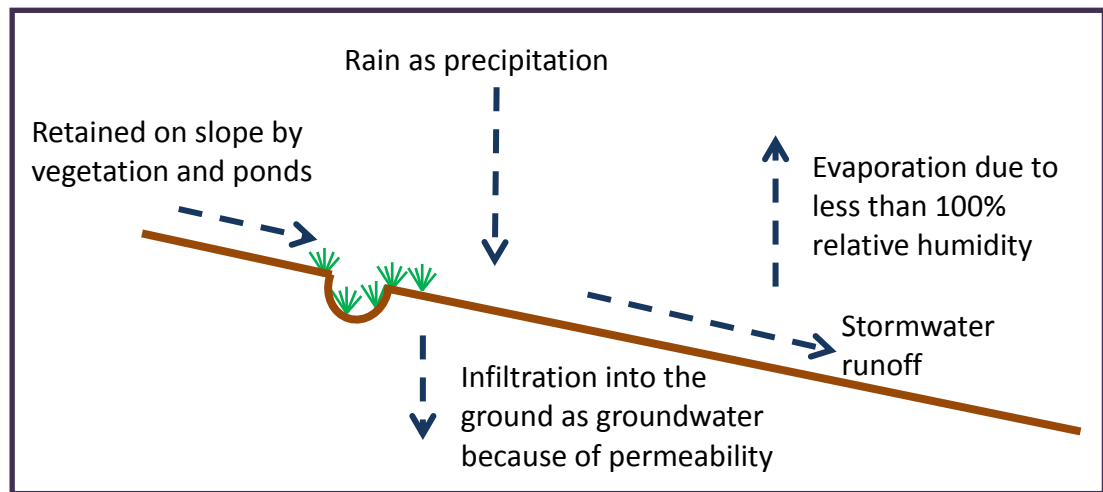


Figure 1.1: Rainfall phenomena

Runoff from precipitation moves through catchment in three ways. They are sheet flow, shallow concentrated flow and stream flow (Baird et al., 2002). According to Baird et al. (2002), sheet flow is defined as the flow with length not more than 300 feet. While shallow flow is started at the point where sheet flow ends. Lastly, the stream flow starts when shallow flow enters a well-defined channel. The flow travel time from the most hydraulically remote point in the contributing catchment area to the point under study is defined as the time of concentration,  $t_c$  (McCuen et al., 1984; JPS, 2001; Baird et al., 2002). The time of concentration can also be defined as the time between the centre of rainfall amount excess the earth and the inflection point on the recession of the direct runoff

hydrograph. Hence, the time different between the end of rainfall excess and the inflection point can be computed by time of concentration (McCuen et al., 1984).

There are three major factors affecting the time of concentration (TR-55, 1986):

- a. surface roughness;
- b. channel shape and flow patterns; and
- c. surface slope.

The Manning's roughness coefficients are always valid to apply in assuming the catchment characteristics (McCuen et al., 1984). There are different methods in calculating both natural catchment and developed catchment. For the natural catchment, the time of concentration is using Bransby-Williams' Equation, which the time for overland flow and stream flow are included. However, for the developed catchment, the time of concentration is the summation of the time of overland flow and the time of travel in the stormwater conveyance system such as drainage systems. In a large study area, time of concentration should be estimated on the basis of locally observed data (JPS, 2000). If the time of concentration is too long, it will create a low peak discharge (under-design) which might result an unsafe condition. Therefore, engineers will limit the length of the sheet flow portion of the total flow path (McCuen et al., 1995).

There are two types of surface runoff channel, i.e. overland flow and well defined conveyor system. Overland flow can be occurred on both unpaved surfaces (such as grasses) and paved surfaces (such as concrete surface). The Friend's Formula is used to estimate overland sheet flow times,  $t_o$  with the overland sheet flow path length is measured by designer and the value of the surface is given (JPS,

2000). The drainage flow time,  $t_d$  is defined as the drain length divided by the average pipe velocity which calculated by using Manning's Equation.

The time of concentration is a variable figure which affects the catchment runoff. A research carried out by Wong (2008) found that channels with longer travel time and large detention storage will produce a smaller outlet discharge. Based on this research, Wong concluded that the channel shape can be used to manage the catchment runoff in order to control the downstream ponding condition. Beside the travel time, the increase in level of discretization will increase the value of time of concentration as well (Pavlovic et al., 2008). This can potentially decrease the outlet discharge.

In the physical point of view, the time of concentration is the time needed for the runoff to travel from the most hydraulically distant point to the catchment outlet. This point is not necessary the point with the longest flow distance, but it is a point with the longest travel time. This point is very depending on the slope and the character of the catchment or the flow path. However in the hydrograph analysis, the time of concentration is the time from the end of excess rainfall to the point of inflection where the recession of the curve begins (Woodward et al., 2010). Other than that, in Rational Method, the time of concentration is equal to the rainfall duration when determining design rainfall intensity (Liang & Melching, 2012).

### **1.3 Problem Statements**

To date, there are two methods to calculate the area of isochrones, i.e. Conventional method and Grid method. Although the Conventional method has been widely practiced by local engineers, this method is still remained with

uncertainty. This method always faces a problem on how to accurately define the area of isochrones from the time of concentration. There could be a number of possible ways to consider in determining the time of concentration to calculate the area of isochrones. In order to calculate the time of concentration, the flow path along which the longest travel time is likely to occur, has to be identified. Often, this process could be very time consuming and tedious. The judgement on how or should the area of isochrones be defined by this methods is too subjective. It is always judged by the experience. The judgement could be very subjective. Therefore the accuracy is relatively low. The Conventional method is time consuming and tedious to be used.

Grid method on the other hand provides a better guide and better precision. It could accurately define the time of concentration. When a set of grid is placed on a site, every grid intersection will be defined by the interpolation of the adjacent terrain elevation points. These points are then collected and re-sampling to calculate the travel time and area of isochrones. However during the process of re-sampling, the closest points are selected manually. This selection of the interpolation could be subjective. This re-sampling process will nonetheless corrupt or downgrade the accuracy.

An example will explain further the Grid method conundrum. Figure 1.2 below shows a part of topography with 1m contour line. A set of grid of 1m spacing is then placed on top of the topography as shown in Figure 1.3. Figure 1.4 shows that in order to calculate the time of concentration, the geometrical characteristic of the interpolation is required. Hence the value of the z-coordinate

value is then assumed. Once the z-coordinates are obtained, the time of concentration could then be calculated, as shown in Figure 1.5. Then, the area of isochrones could be generated as shown in Figure 1.6. Table 1.1 shows a tabulation of the area between the isochrones.

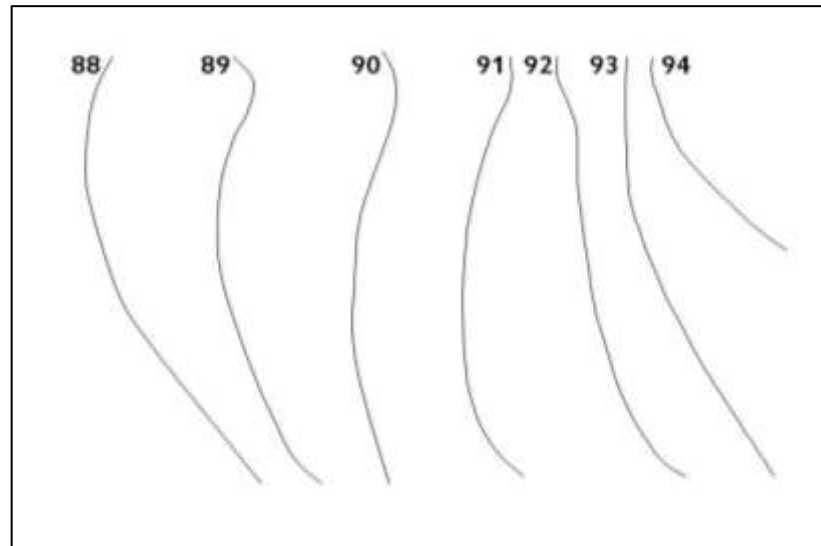


Figure 1.2: Topography with 1m contour line

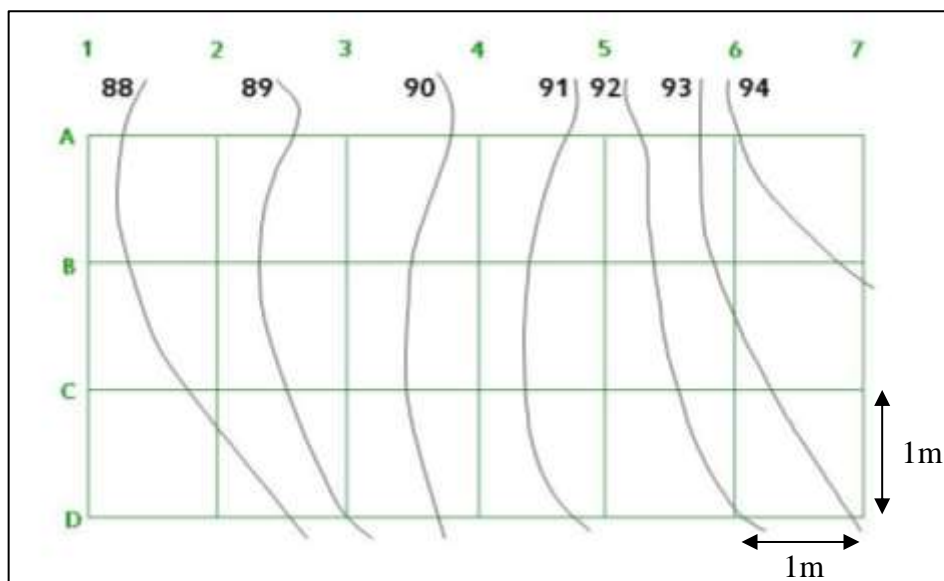


Figure 1.3: Superimpose of grid and contour line